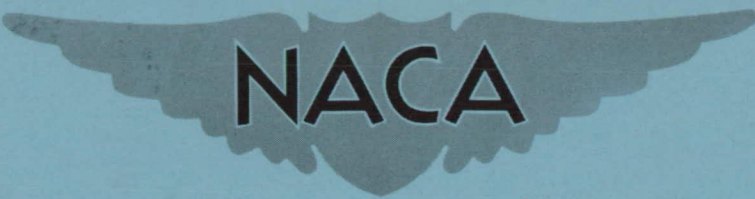


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NACA

RESEARCH MEMORANDUM

ERROR IN AIRSPEED MEASUREMENT DUE TO STATIC-PRESSURE
FIELD AHEAD OF AN OPEN-NOSE AIR-INLET MODEL
AT TRANSONIC SPEEDS

By Thomas C. O'Bryan

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NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

WASHINGTON
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RESEARCH MEMORANDUM

ERROR IN AIRSPEED MEASUREMENT DUE TO STATIC-PRESSURE
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SUMMARY

As a part of a study of means of airspeed measurement at transonic speed, studies have been made at Mach numbers from 0.7 to 1.1 by the NACA wing-flow method of the static-pressure coefficient ahead of an open-nose air-inlet body at zero angle of attack.

It was found that the static-pressure coefficient ahead of the inlet, at constant inlet-velocity ratio, is relatively independent of Mach number below 0.90 and varies inversely with the square of the distance ahead of the inlet.

An average decrease in inlet-velocity ratio of 0.1 resulted in an increase of approximately 0.02 in the pressure coefficient at 1.5 inlet diameters ahead of the inlet, for the Mach number range tested. The Mach number for shock passage was increased approximately 0.02 by this decrease in inlet-velocity ratio.

Calculations of the static-pressure coefficient ahead of a number of NACA 1-series inlets have been made for incompressible flow and have shown that, for inlets of constant ratio of inlet diameter to maximum diameter (d/D), the static-pressure coefficient is unaffected by the ratio of length to maximum diameter (X/D). The static-pressure coefficient was found to be a function of distance ahead of the inlet (x/d), and inlet-velocity ratio only.

The calculated static-pressure coefficient ahead of inlets for which the ratio of inlet diameter to maximum diameter varied was found to decrease for a given inlet-velocity ratio as the inlet becomes larger with respect to maximum diameter.

INTRODUCTION

The location of a source of static pressure for airspeed measurement in transonic flight has received considerable attention with the advent of aircraft operating at these speeds. Conventional (subsonic) locations of static-pressure measurement are in general undesirable at transonic speeds due to large and abrupt changes in the indicated pressure. Previous investigations (references 1 and 2) have dealt for the most part with specific configurations. However, a generalized study of nose-boom installations ahead of sharp-nosed bodies has been made in reference 3. Results of reference 3 indicated that nose-boom airspeed installations are the most suitable for sharp-nose bodies.

Nose air inlets are widely used on aircraft to obtain the best pressure recovery for turbojet engines. The present investigation, which was performed by means of the NACA wing-flow method, was undertaken to extend the results of reference 3 to determine the effects of nose air inlets on the characteristics of nose-boom airspeed installations.

Results of the investigation are presented as variations with Mach number of the static-pressure coefficient at several positions ahead of an open-nose air inlet for a small range of inlet-velocity ratios. The Mach number range covered is from 0.70 to 1.10.

The experimental results for $M = 0.70$ are compared with theoretical calculations for incompressible flow and results of further computations are presented to provide information on the effect of changing inlet geometry.

SYMBOLS

D	maximum diameter of nose inlet body
d	inlet diameter
d/D	inlet-diameter ratio
X	nose-inlet length, measured from inlet to maximum-diameter station
X/D	length to diameter ratio
x	axial distance ahead of nose of body

x/d	axial distance ahead of inlet expressed as a fraction of the inlet diameter
M_T	true Mach number
V_i	velocity at the inlet
V_o	free-stream velocity
p	local static pressure
p_o	free-stream static pressure (at model position)
q_c	dynamic pressure (at model position)
P	pressure coefficient $\left(\frac{p - p_o}{q_c} \right)$

MODEL

The model, shown by a photograph in figure 1 and a drawing giving details and dimensions in figure 2, was a nose-air-inlet body mounted centrally on a sting. The forebody was an NACA 1-50-150 inlet fairing into an elliptical afterbody. The body was equipped with a cone-pointed static-pressure tube of 0.060 inch diameter extending forward axially from the inlet. This tube was adjustable fore and aft and carried four 0.020-inch-diameter orifices located 0.30 inch (5 tube diameters) behind the shoulder of the cone point. One 0.020-inch orifice was located on the sting, in the inlet, 0.88 inch behind the nose. This orifice measured the static pressure in the duct, from which inlet-velocity ratios were obtained.

Modifications to the model, shown in figure 2, were made to change the inlet-velocity ratio for different tests. The inlet-velocity ratio was decreased by restricting the exit area with a plug. Increased inlet-velocity ratio was obtained by increasing the exit area and installing an exit flap.

METHOD

A photograph of the model mounted over the specially faired ammunition compartment door on the F-51 airplane is shown as figure 3. The model was mounted 6 inches above and parallel to the test section and was aligned laterally with the local flow.

The static pressure measured at the positions of the orifices on the boom and the orifice in the duct, without the model in place, was calibrated with respect to the static pressure measured by a reference tube located sufficiently far forward and to the side of the model so as to be unaffected by the flow over the model. This calibration was used to obtain free-stream static pressure at model station. The reference static tube which is shown to the right of the model in figure 3 was also used to provide a reference Mach number as in reference 3. The inlet-velocity ratio was calculated by use of Bernoulli's equation for compressible flow utilizing the measured static pressure in the duct and the free-stream Mach number.

The instrumentation and test procedure were similar to that of reference 3 and the tests covered a Mach number range of 0.70 to 1.10.

RESULTS AND DISCUSSION

Experimental

The variations of inlet-velocity ratio with true Mach number for the tests made with the static-pressure orifices at 1.5 and 4.0 inlet diameters ahead of the inlet (the only positions for which inlet-velocity ratio was determined) are shown in figure 4. The differences in inlet-velocity ratio for different locations of the static-pressure measurement ahead of the inlet for the design configuration are small and it is presumed that the same small variations would be measured for the intermediate locations of static-pressure measurement ahead of the inlet.

The variation of static-pressure coefficient with true Mach number at several positions ahead of the inlet is shown in figure 5. The inlet-velocity ratios for this configuration vary from about 0.68 at $M = 0.70$ to 0.50 at $M = 1.10$. The static-pressure coefficient is relatively independent of Mach number below 0.90 and varies approximately inversely with the square of the distance ahead of the inlet. Above Mach number 0.90 the pressure coefficient rises rapidly; the rise is greater as the measurement location is moved nearer the inlet. The pressure coefficient continues to rise until the Mach number at which the body bow wave crosses the orifices is reached whereupon the pressure coefficient drops abruptly to zero.

The variation with Mach number of the pressure coefficient across a normal shock, shown in figure 5, indicates that the pressure discontinuity occurred at a lower Mach number (approximately 0.02) than that predicted by normal-shock theory. This disagreement between

theory and experiment is similar to that described in reference 3. No explanation, however, has been found for this disagreement.

The effect of inlet-velocity ratio on the static-pressure coefficient 1.5 inlet diameters ahead of the inlet is shown in figure 6 as a function of true Mach number. The configuration intended to increase the inlet-velocity ratio resulted in very little change from the design-configuration inlet-velocity ratio (fig. 4). This is reflected in figure 6 in that there is apparently no change in the static pressure ahead of the inlet from that of the design configuration. The configuration for reduced inlet-velocity ratio is seen in figure 4 to have resulted in an average decrease of 0.1 inlet-velocity ratio for the Mach number range covered. The effect of this decrease in inlet-velocity on the static pressure ahead of the inlet (fig. 6) resulted in an increase of approximately 0.02 in the static-pressure coefficient throughout the Mach number range. The Mach number for shock passage was increased approximately 0.02.

Effect of Inlet Geometry

In order to determine the effect of inlet geometry on the static-pressure coefficient ahead of open-nose air inlets, theoretical calculations were made of the pressure coefficient at several locations ahead of a number of NACA 1-series open-nose air inlets. A method is presented in reference 4 whereby the static-pressure coefficient ahead of open-nose inlets in incompressible flow may be calculated using experimental surface pressure distributions. The theoretical calculations were made at zero angle of attack for the inlets, utilizing the surface pressure distributions of reference 5.

Figure 7 presents the calculated variation of pressure coefficient ahead of three NACA 1-series inlets of constant ratio of inlet diameter to maximum diameter ($\frac{d}{D} = 0.5$) at several locations ahead of the inlet, for an inlet-velocity ratio range of 0.2 to 1.0. It is clear from figure 7 that for the 1-series inlets of constant ratio of inlet diameter to maximum diameter the pressure ahead of the inlets is a function of inlet-velocity ratio and location (x/d) ahead of the inlet only. The static pressure ahead of the inlet is apparently independent of the length factor (X/D). The most pronounced variation in pressure coefficient with inlet-velocity ratio occurred close to the inlet as is evidenced by the slope of the pressure-coefficient curve obtained from the location 1 inlet diameter ahead of the inlet. The magnitude of the variation of pressure coefficient with inlet-velocity ratio decreased with distance ahead of the inlet until (at $\frac{x}{d} = 4.0$) the pressure coefficient varied only from 0.005 to 0.01 as the inlet-velocity ratio was

decreased from 1.0 to 0.2. At all values of x/d shown on figure 7 a reduction of inlet-velocity ratio from 1.0 to 0.2 caused the pressure coefficient ahead of the inlet to approximately double.

The static-pressure coefficient ahead of three l-series inlets, in which the ratios of inlet diameter to maximum diameter and of maximum diameter to length were varied, is presented in figure 8. It is apparent from figure 8 that as the inlet increases in diameter with respect to the maximum diameter the static-pressure coefficient decreases for a given inlet-velocity ratio and that this decrease is most pronounced for the position nearest the inlet. This analysis neglects the consideration of the effect of differences in the ratio of length to maximum diameter; however, it was shown in figure 7 that changes in this ratio had no effect on the pressure ahead of the inlet.

Comparison with Theory

The effect of an NACA 1-50-150 nose inlet on the static-pressure coefficient at several locations ahead of the inlet is compared with calculations made by vortex-sheet theory (reference 4) in figure 9. The experimental data are those obtained by using the design configuration with measurements at 1.0, 1.5, 2.0, and 4.0 inlet diameters ahead of the inlet. The experimental data used were for the lowest Mach number tested ($M = 0.70$) and for an inlet-velocity ratio of 0.68.

The comparison in figure 9 indicates that the theory underestimates the measured static-pressure coefficient an average of 2.5 percent of of q_c .

Estimation of Pressure Coefficient

The static-pressure coefficient to be expected ahead of inlets in incompressible flow can be estimated from figures 7 and 8. It has been shown in figure 9 that the theoretical variation of static-pressure coefficient with distance ahead of the inlet, for incompressible flow, agreed within 2.5 percent of q_c with the experimental variation obtained for the NACA 1-50-150 inlet at a Mach number of 0.7. The results of the incompressible-flow theory given in figures 7 and 8 are therefore presumed to give the approximate pressure coefficient to be expected ahead of other l-series inlets at a Mach number of 0.7. If a knowledge of the low-speed pressure coefficient is thus obtained, figure 5 can be used to estimate the increase in pressure to be expected at transonic speeds and the Mach number at which to expect the fuselage bow wave to cross the static-pressure orifices.

CONCLUSIONS

Measurements made by the wing-flow method at Mach numbers from 0.7 to 1.1 of the static pressure ahead of an open-nose air-inlet body (NACA 1-50-150 inlet) at zero angle of attack have indicated that:

1. The static-pressure coefficient at constant inlet-velocity ratio is relatively independent of Mach number for Mach numbers below 0.9 and varies approximately inversely with the square of the distance ahead of the inlet. At Mach numbers above 0.9 the pressure coefficient increases rapidly and at slightly supersonic speeds drops abruptly to zero as the body bow wave passes over the orifices.

2. An average decrease in inlet-velocity ratio of 0.1 resulted in an increase of approximately 0.02 in the static-pressure coefficient at 1.5 inlet diameters ahead of the inlet for the Mach number range tested. The Mach number for shock passage was increased approximately 0.02 by this decrease in inlet-velocity ratio.

Calculations of static-pressure coefficient ahead of a number of NACA 1-series inlets for incompressible flow indicate that:

1. The static-pressure coefficient is unaffected by the ratio of length to maximum diameter (X/D). The pressure is a function of distance ahead of the inlet (x/d) and inlet-velocity ratio only, for inlets having their ratio of inlet diameter to maximum diameter (d/D) constant.

2. The static-pressure coefficient ahead of inlets, for which the ratio of inlet diameter to maximum diameter is varied, decreases for a given inlet-velocity ratio as the inlet becomes larger with respect to the maximum diameter.

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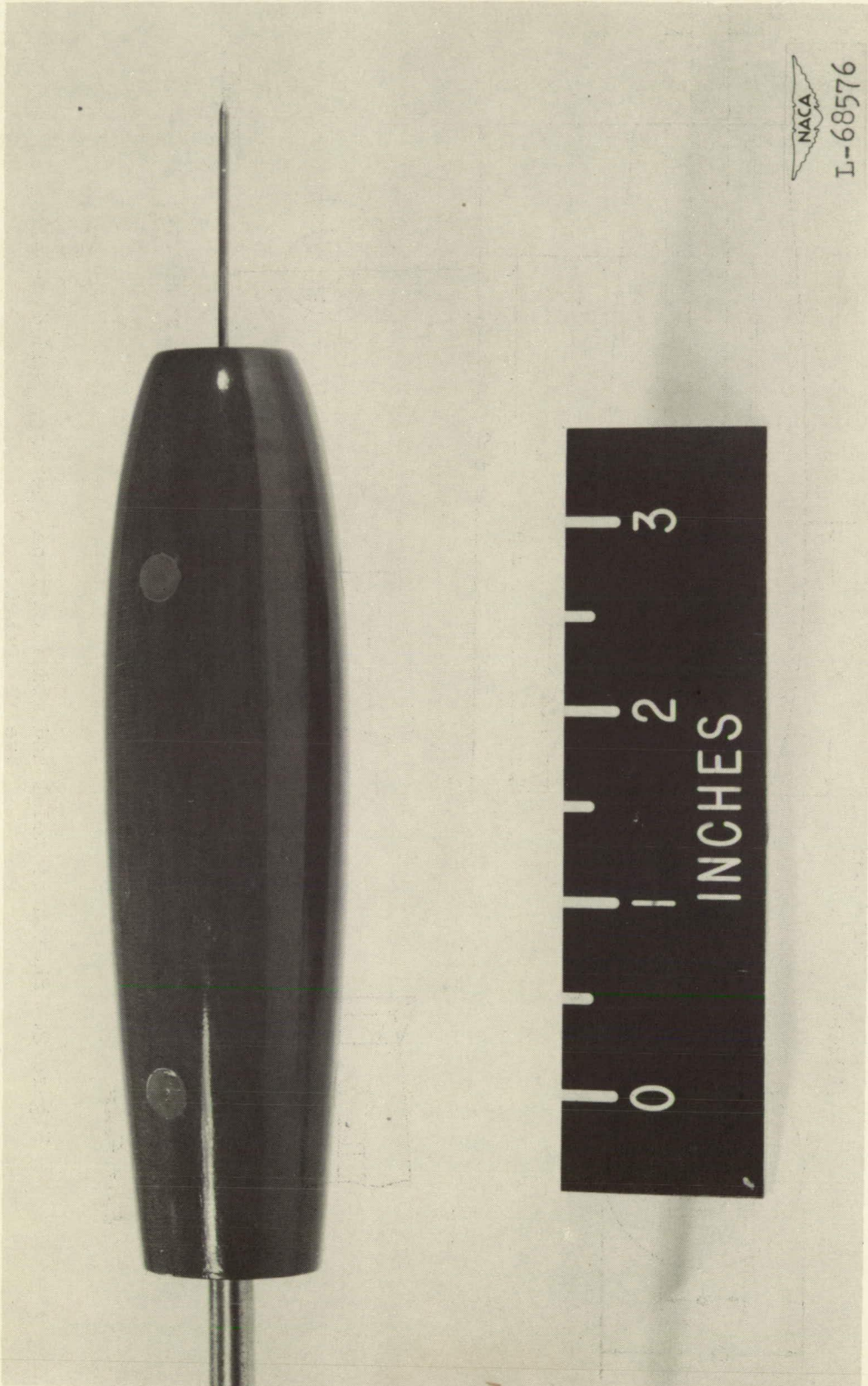
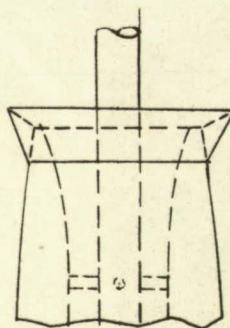
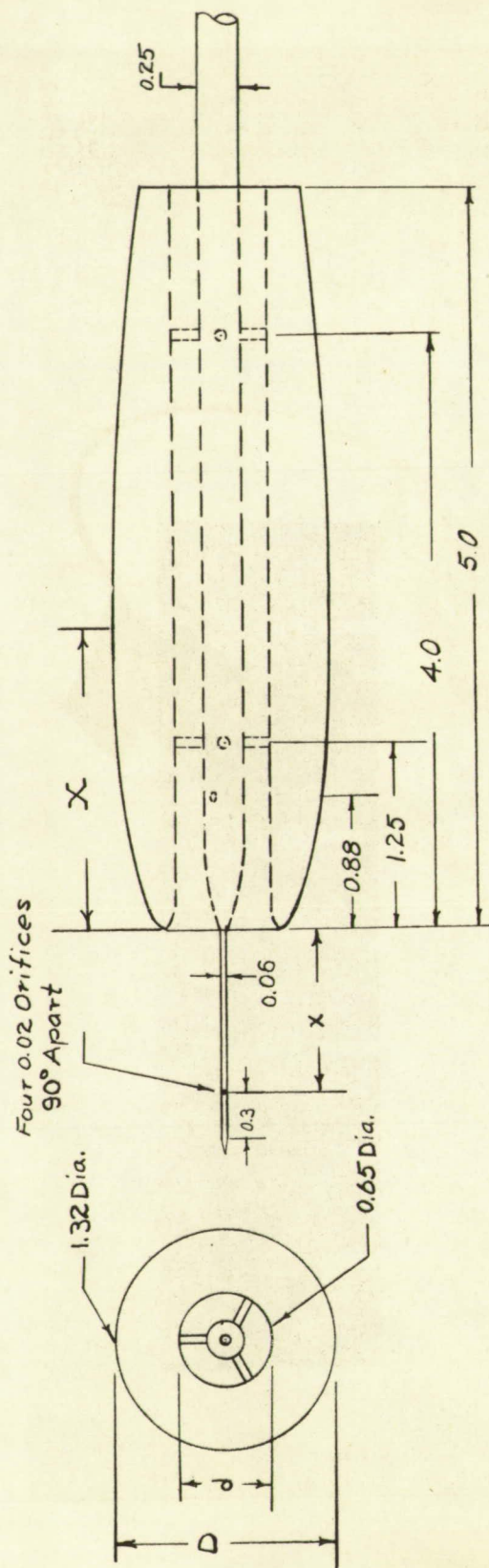
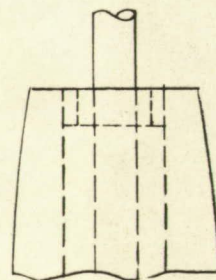


Figure 1.- Photograph of model.

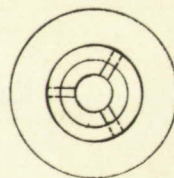
DESIGN CONFIGURATION



INCREASED EXIT AREA
AND
EXIT FLAP



DECREASED EXIT AREA



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Figure 2.- Sketch of model and modifications thereof. All dimensions are in inches.

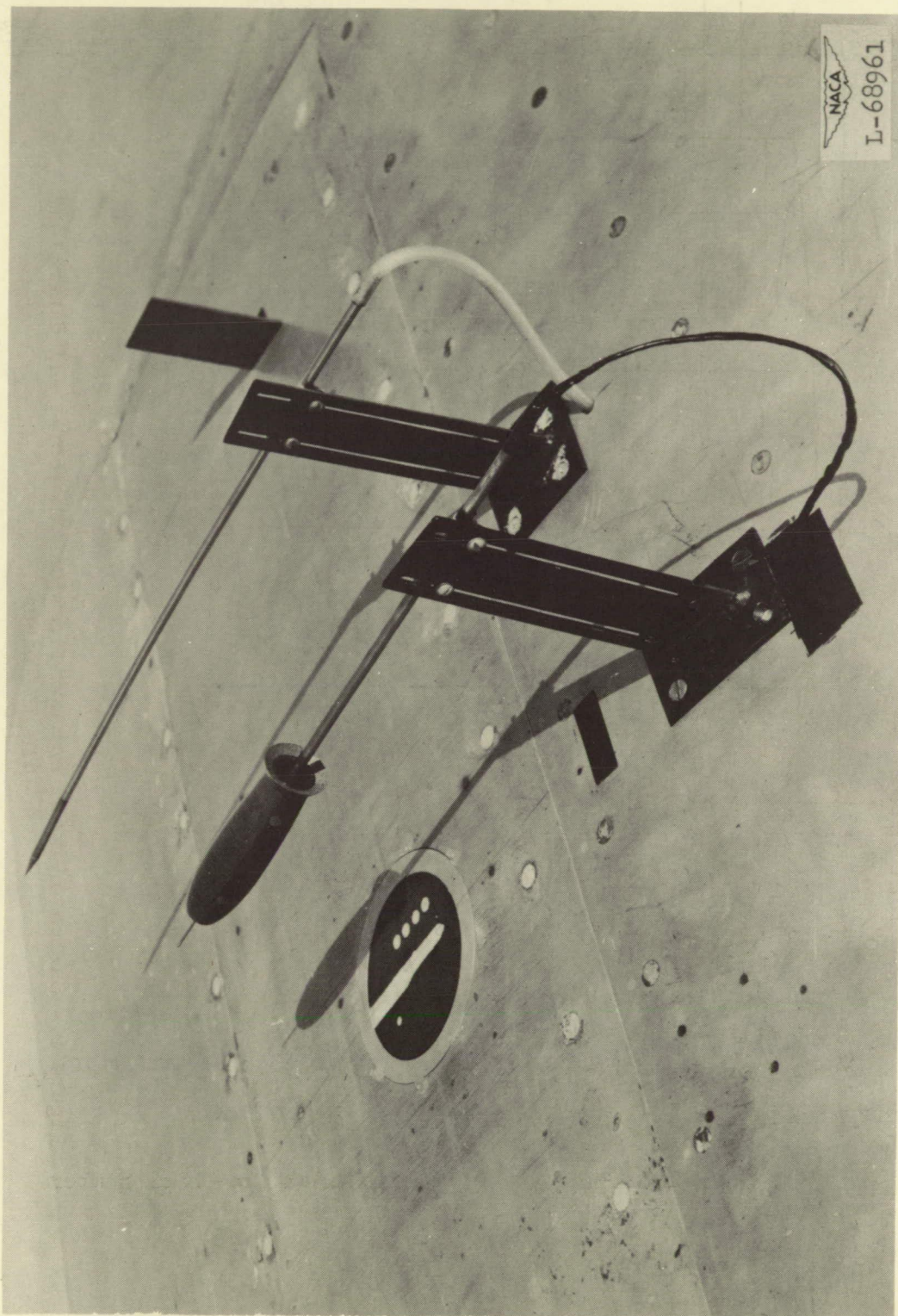
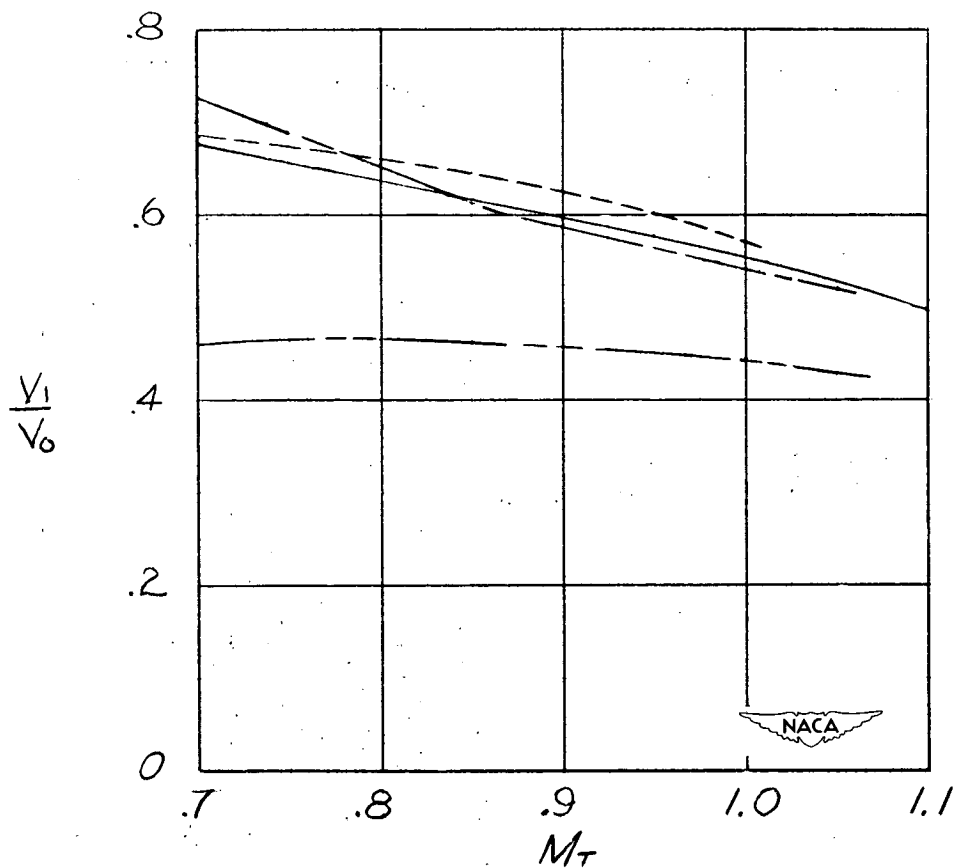


Figure 3.- Photograph of model and reference static tube mounted on wing-flow test panel.



Orifice Location	Configuration
$\frac{x}{d}$	
————— 1.5	Design
----- 4.0	Design
— · — · — 1.5	Increased Exit Area + Exit Flap
— · — · — 1.5	Reduced Exit Area

Figure 4.- Variation of inlet-velocity ratio with true Mach number.

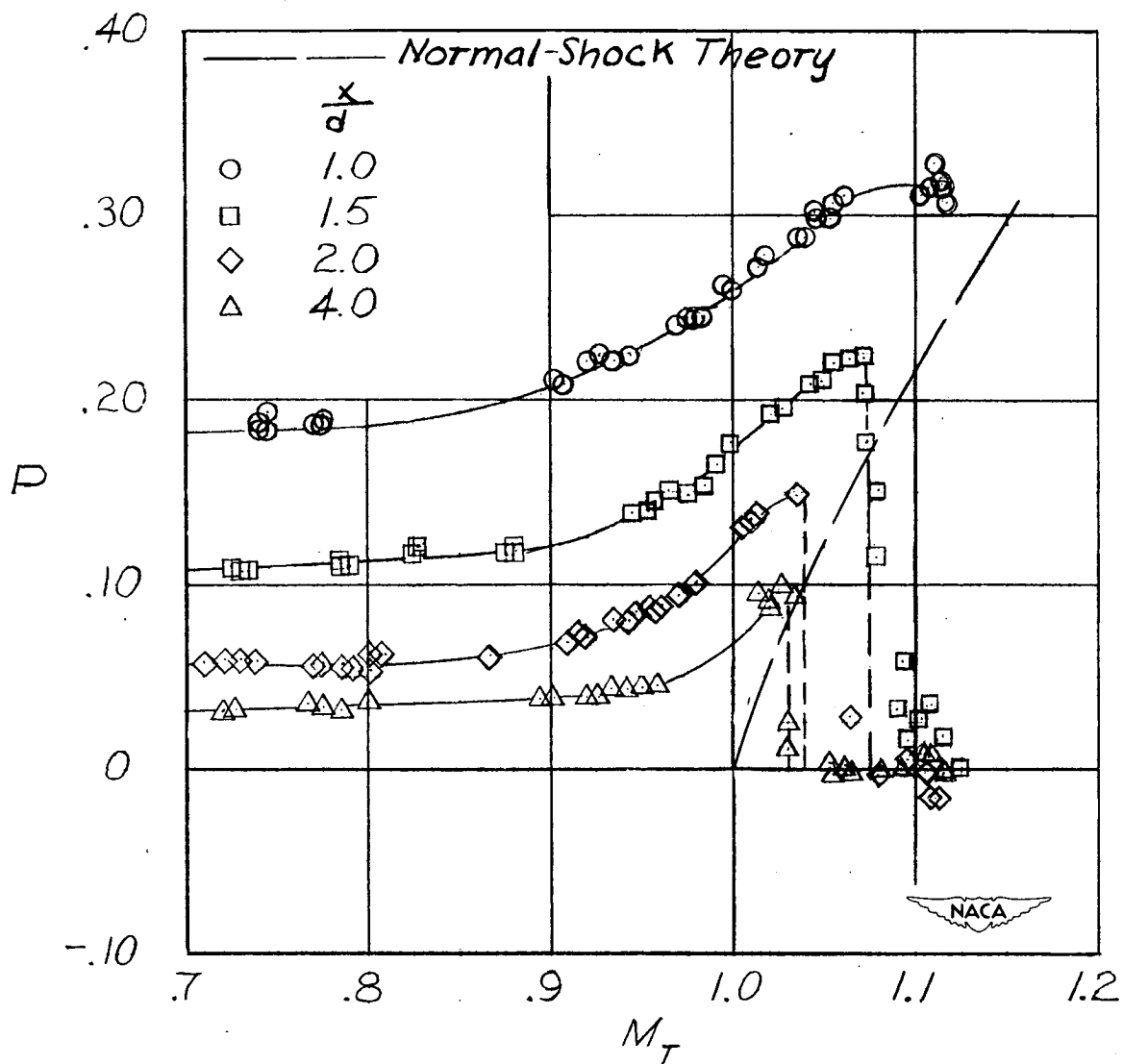


Figure 5.- Variation of static-pressure coefficient ahead of inlet.

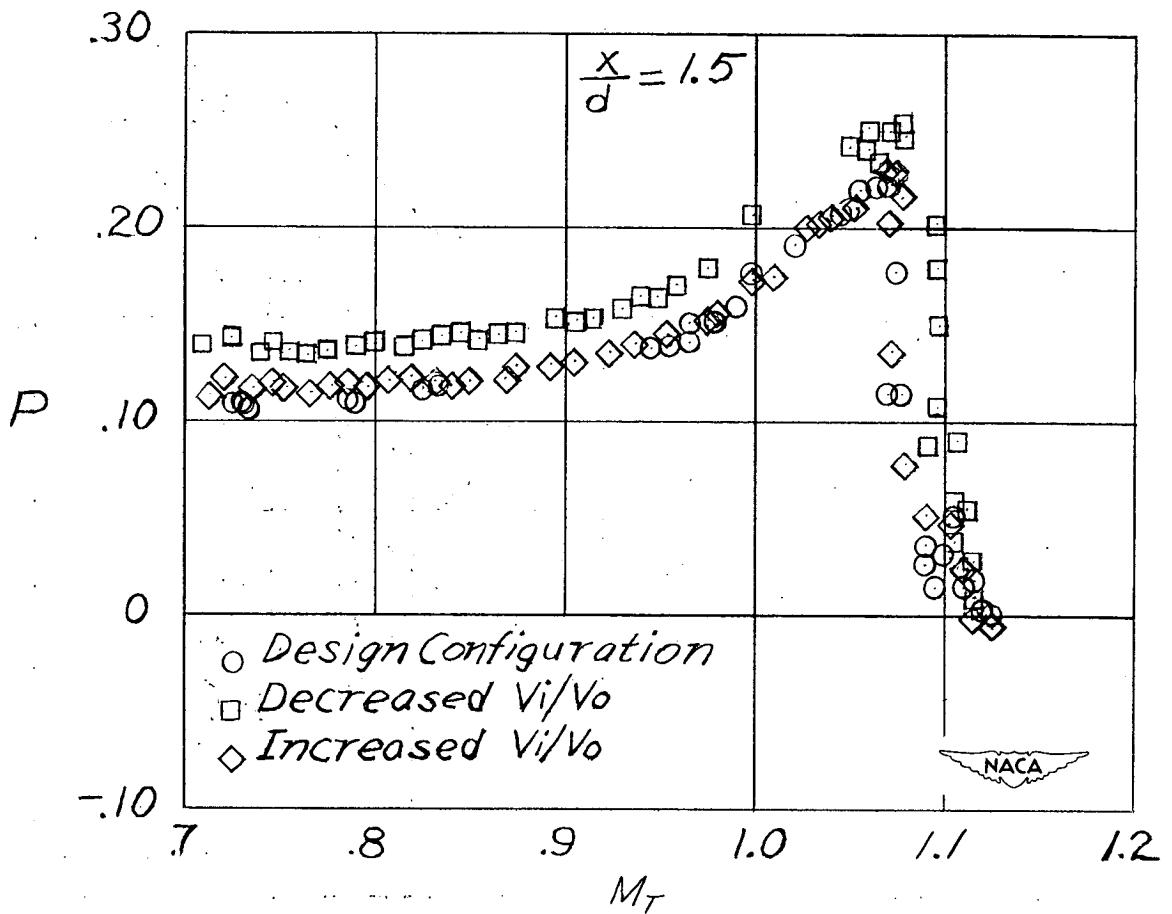


Figure 6.- Effect of inlet-velocity ratio on static pressure ahead of inlet.

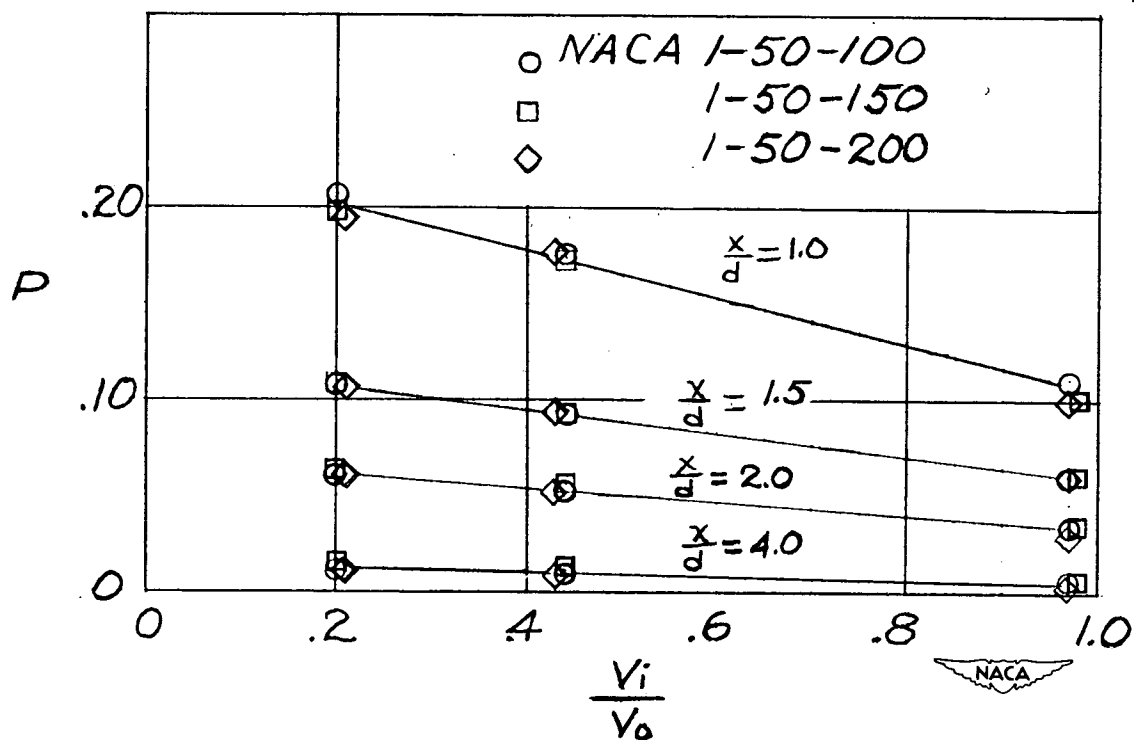


Figure 7.- Calculated variation of static-pressure coefficient with inlet-velocity ratio at a number of inlet diameters ahead of three NACA 1-series inlets (NACA 1-50-100, 1-50-150, 1-50-200).

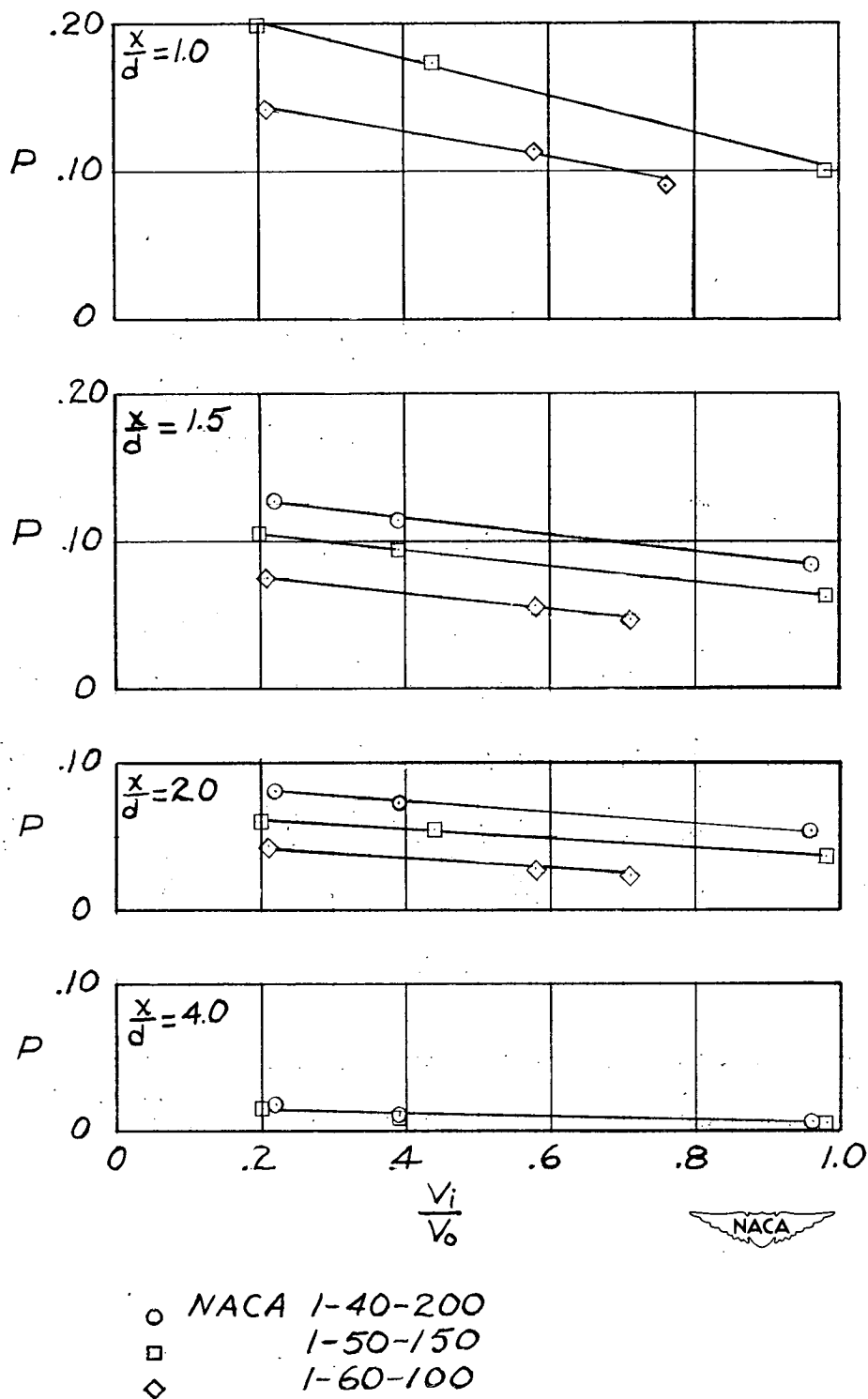


Figure 8.- Calculated variation of static-pressure coefficient with inlet-velocity ratio at a number of inlet diameters ahead of three NACA 1-series inlets. (NACA 1-40-200, 1-50-150, 1-60-100).

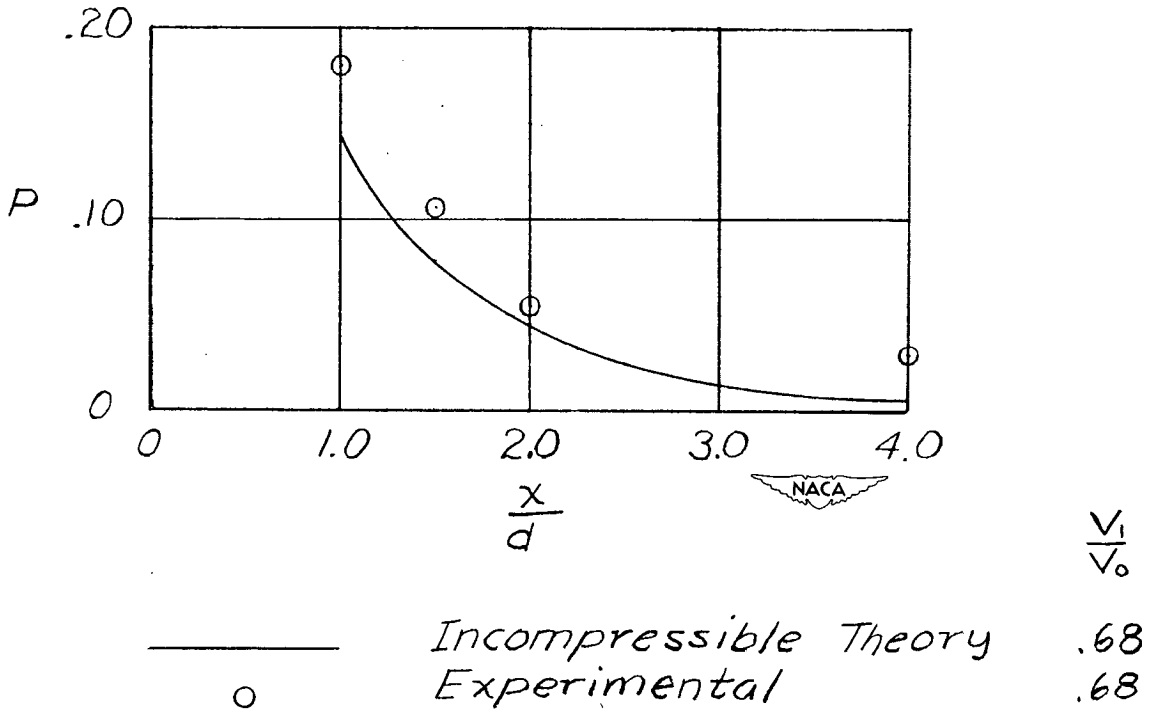


Figure 9.- Comparison of the experimental result at Mach number 0.70 with static pressure ahead of the inlet as calculated from reference 4.